Mie scattering based high-Q cavity

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Mie scattering [1] elucidates the interaction of light with particles whose dimensions are comparable to the wavelength, resulting in electric dipole (ED), magnetic dipole (MD), and higher-order modes. The Kerker conditions [2] are realized when ED and MD modes interfere either in-phase or out-of-phase, enabling directional scattering. These principles have been widely exploited in metasurface [3] design to control light propagation, transmission, reflection, yet their application to cavities remains unexplored.

We calculated the scattering cross-section of a silicon cylinder with infinite extent along the z-axis. The cylinder with a radius of 200 nm exhibits an ED peak at 1220 nm and an MD peak at 1860 nm. In the spectral region between these two peaks, specifically from 1326 nm to 1724 nm, we observed high reflectance approaching unity, attributed to a high backward-to-forward scattering ratio. Furthermore, for a cylinder with a radius of 170nm, the MD peak is observed at 1557 nm. Based on these findings, we propose a cavity design in which a 170 nm radius cylinder is centrally positioned, encircled by 200 nm radius cylinders arranged in a circular configuration. This structure can confine light as an MD-like cavity mode with a wavelength of 1550 nm.

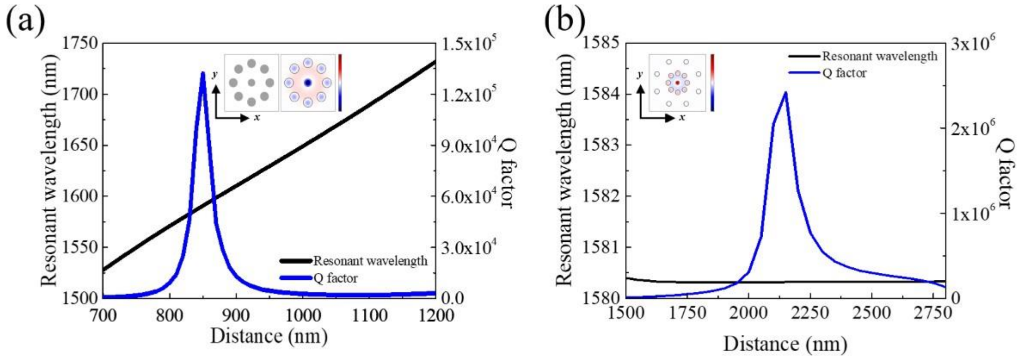

Figure 1. Q factor and resonant wavelength as a function of the distance between 170 nm cylinders and the surrounding cylinders in the configurations: (a) 8 surrounding cylinders and (b) with additional outer layer of 8 cylinders.

We systematically varied the number of cylinders with a radius of 200 nm and adjusted the distance between the central cylinder, with a radius of 170 nm, and the surrounding 200 nm-radius cylinders to optimize the Q factor, which characterizes the resonance behavior of the cavity. When eight cylinders with a radius of 200 nm were positioned at a distance of 850 nm from the central 170 nm-radius cylinder, the highest Q factor of 1.3×10^5 was achieved at a wavelength of 1580 nm. To further enhance performance, additional 200 nm-radius cylinders were incorporated into the structure as an additional outer layer, resulting in a significantly improved Q factor of 3.51×10^6 at 1580 nm. The overall dimensions of the structure are approximately 4400 nm × 4400 nm, corresponding to ~2.9 λ × 2.9 λ (where λ = 1580 nm). A high Q factor was achieved due to efficient light confinement in the transverse plane based on the strong backscattering property of Mie resonances.

References

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